Parameter	Symbol	Unit	Value			Method of Determination
			Reach 1	Reach 2	Reach 3	
Dispersion coefficient		km^2/day	10,0	0,4	10,0	Assumed same as for March survey
Decay coefficient	K_1	1/day	0,1	1,3	1,0	Model fitting
Reaeration coefficient	K_2	1/day	2,0	2,7	5,0	Reaches 1 and 2 - formula 7.4 Reach 3 - model fitting
BOD source/sink (1)	S	mg/l/day	-32	175	50	Model fitting
DO source/sink (2)	R_1	mg/l/day	-13	13	-15	Model fitting
Photosyntnesis DO (2)	P_1	mg/l/day	3	5	5	Model fitting
Inert source/ sink (1)		mg/l/day	-48	20	50	Model fitting

Notes: (1) A negative value indicates a source (positive being a sink).
(2) A positive value indicates a source (negative being a sink).

The inert fraction of the COD was taken as 60%.

TABLE 8.2 Results of model fitted to COD data of 18 July 1978

8.4 Calibration by minimising the error

Stephenson (1979) has demonstrated how linear programming techniques can be used for automatic calibration of a model by minimising the sum of the absolute errors between the observed and simulated values. This technique is discussed in Appendix A4.

The finite difference form of the equations required for this procedure are derived in Appendix A4 and shown below in aquation 8.1.

The linear constraints in the case of BOD are:

$$C1\ L_{i,n+1} + C2\ L_{i+1,n-1} - C2\ L_{i,n} - C1\ L_{i+1,n}$$

$$- \quad (b_{i,n-1} + b_{i+1,n-1} + b_{i,n} + b_{i+1,n})\frac{K1_i \Delta t}{4}$$

$$+ \quad \Delta t\ S_i - \Delta t\ T_i \quad = 0 \qquad 8.1a$$

$$L_{i,n} + U_{i,n} - V_{i,n} \quad = b_{i,n} \qquad 8.1b$$

Where $C1 = (\frac{1}{2} + \frac{U}{2}\frac{\Delta t}{\Delta x})$

$C2 = (\frac{1}{2} - \frac{U}{2}\frac{\Delta t}{\Delta x})$

and $L_{i,n}$ = calculated BOD concentration at station i and time n.

$b_{i,n}$ = observed BOD concentrations at station i and time n.

$K1_i$ = BOD decay coefficient for the subreach above station i.

S_i, T_i = sources and sinks of BOD along the subreach above station i.

$U_{i,n}, V_{i,n}$ = error in calculated BOD at station i and time n.

U = mean velocity along the subreach upstream of station i.

For DO the linear constraints are:

$$C1\ C_{i,n-1} + C2\ C_{i+1,n-1} - C2\ C_{i,n} - C1\ C_{i+1,n}$$

$$- (b_{i,n-1} + b_{i+1,n-1} + b_{i,n} + b_{i+1,n})\ \frac{K1_i \Delta t}{4}$$

$$+ \left[C_s - \frac{1}{4}(d_{i,n-1} + d_{i+1,n-1} + d_{i,n} + d_{i+1,n})\right] K2_i \Delta t$$

$$+ \Delta t\ P_i - \Delta t\ R_i = 0 \qquad 8.1c$$

$$C_{i,n} + M_{i,n} - N_{i,n} = d_{i,n} \qquad 8.1d$$

Where $C_{i,n}$ = calculated DO concentrations at station i and time n.

$d_{i,n}$ = observed DO concentrations at station i and time n.

$K2_i$ = reaeration coefficient for the subreach above station i.

P_i, R_i = sources and sinks of DO along the subreach above station i.

$M_{i,n}, N_{i,n}$ = error in calculated DO at station i and time n.

The above equations do not include the dispersion term, nor in this case do they allow for diurnal variations of photosynthetic DO and inert fractions in the case of COD.

The principle of the method is to minimise the sum of the absolute values of the differences between the calculated and observed concentrations of BOD and DO, thereby establishing the values of the unknown parameters giving the best fitting model. Linear programming techniques are used to achieve this, and, since for linear programming the variables must all be positive, two error terms are used in equations 8.1b and 8.1d for which one will be zero in the final solution. Similarly the source/sink terms are represented by two variables. The objective function of the system of equations then becomes:

$$\text{Minimise} \left\{ \sum_n \sum_i (U_{i,n} + V_{i,n} + M_{i,n} + N_{i,n}) \right\}$$

subject to the equality constraints given by equations 8.1.

This calibration method was tested using the COD data from the sampling survey of 21 March 1979. The quantity of data was immense with the number of variables being 594 and the total number of constraint equations, given by equations 8.1, being 330. The data preparation was, however, facilitated considerably by the simple patterns of the coefficient matrix and the whole process could be completed by one person in about four days.

The IBM/370 package program, 'Mathematical Programming System Extended' (M.P.S.X.), was used to carry out the linear programming analysis and the results obtained for the system parameters are listed in table 8.3.

	COD decay coefficient K1(day^{-1})	Reaeration coefficient K2(day^{-1})	COD source/ sink term[$] S(mg/l/day)	DO source/ sink term[$] P(mg/l/day)
Reach E-F	0,49	0	+ 169	+ 35
Reach F-G	0,28	0	- 461	+ 18
Reach G-H(a)	0	0,94	- 98	+ 2

$: +ve indicates a source, -ve a sink

TABLE 8.3 Parameters obtained using minimum error calibration

These parameters were then used in the simulation model and the results are plotted in figure 8.7.

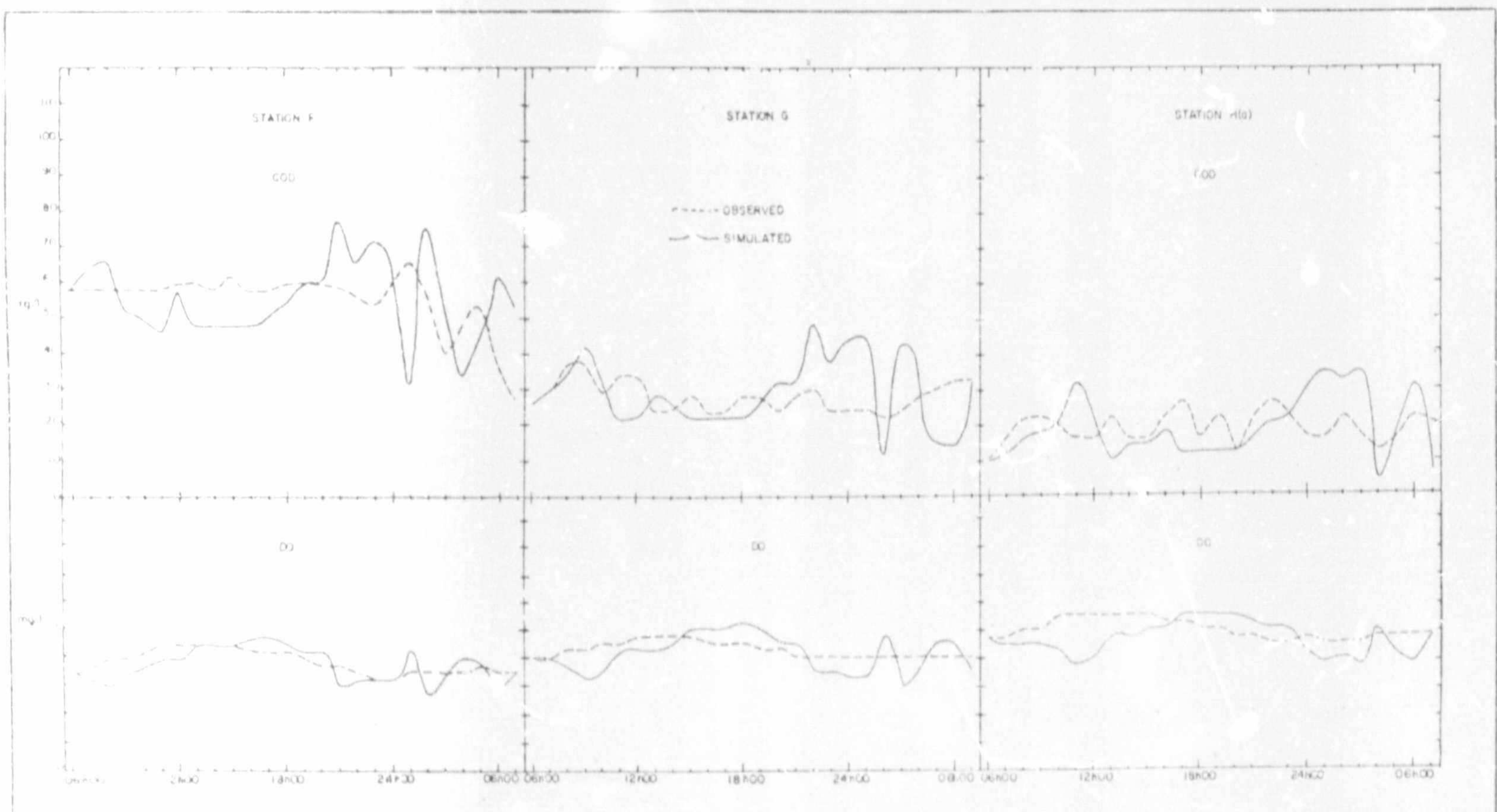

Figure B-7 — Results of Simulation Using Minimum Error Calibration Parameters.

CHAPTER 9

DISCUSSION OF THE SIMULATION MODEL AND RESULTS

9.1 The computer model KLIP6

The two-step explicit finite difference method used in the model KLIP6 apparently gives a slightly different output response from that of the standard difference method used in an earlier version of the model (KLP3). The two methods are both described in detail in Appendix A2, along with the problems associated with the standard method that the two-step method overcomes.

In the two-step method, no stability problems arise from the magnitude of the flow velocity U, since $\Delta x / \Delta t$ is always equal to U. In the other hand this could have some disadvantages in a more sophisticated model which allowed for variations in flow in the river, as the finite difference grid would have to be continually changing. (In such cases it would be preferable to vary the time interval rather than the space interval and compute the full simulation for each reach in turn, using the results of the immediate upstream reach as input). Stability of the calculation involving the other terms is possible through the suitable choice of the integer value by which the time step is divided to reduce the $\Delta t / \Delta x$ ratio.

A comparison of the running times for the two finite difference techniques indicates that the computation time for the two-step method is slightly less than for the standard method. This results from the fact that the critical time step for stability of the standard method is smaller than that for the two-step method as shown by the relationships A2.2 and A2.4 in Appendix A2.

Tests with hypothetical triangular and step inputs showed that the model was responding correctly to various parameter changes; however, in applying the model to the real system, it is important to bear in mind the following basic assumptions in the formulation:

(i) First-order BOD decay reaction

The first-order BOD decay reaction used in the model assumes that the decay rate is proportional to the BOD concentration. This is considered acceptable for low BOD levels and representative for most stream conditions (Eckenfelder and O'Connor, 1961, p.124), although some researchers have used second-order approximations to the decay curve for wastewaters (Eckenfelder, 1970, p.160) depending on the substrate mixture. The first order reaction is in fact the resultant of a set of simultaneously occurring zero-order reactions as indicated in figure 9.1 below (Eckenfelder, 1970, p.161):

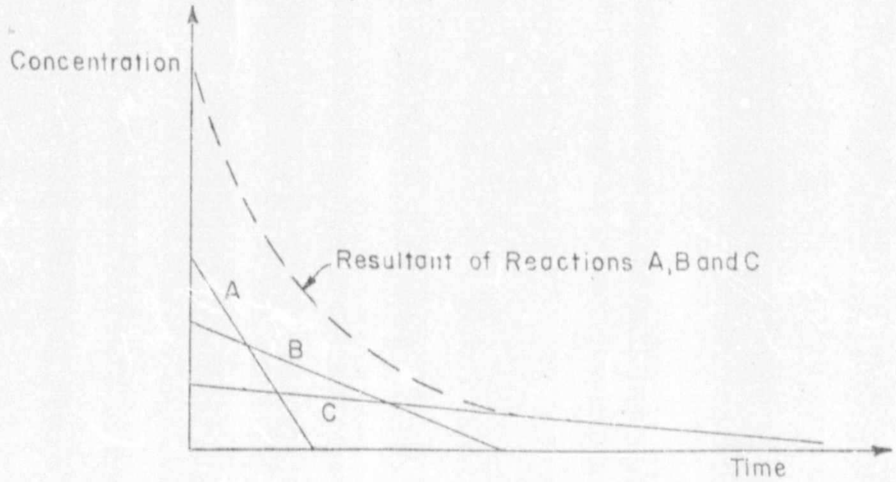

Figure 9.1 Graph illustrating the component reactions making up the first order reaction curve

In the river environment the decay coefficient is usually different from that found in the laboratory. This difference can be attributed to external factors affecting the rate of oxidation of organic matter such as turbulence, biological extrac n, immediate demands, nutrients and time lags, and to factors affecting the removal of organic matter, i.e sludge deposit and scour and volatilisation (Eckenfelder and O'Connor, 1961). The methods by which some of these factors were allowed for in the model were detailed in section 4.6, the factors affecting the oxidation rate being incorporated into a resultant decay coefficient and those affecting removal being treated as sources and sinks.

The factors affecting oxidation rates are sometimes separated from the laboratory determination of k_1' so that

$$K_1 \text{ (river)} = k_3 + k_1' \text{ (laboratory)}$$

(Eckenfelder and O'Connor, 1961).

The value of k_1' is then determined by laboratory experiment leaving k_3 to be determined through calibration of the model. This method has the advantage in that an idea of the secondary factors involved in the river environment is obtained.

(ii) The rates of deoxygenation and BOD decay are equal

This assumption holds provided that the effective rate of oxidation of organic matter is used as described above, and not the laboratory determined value.

(iii) The reoxygenation rate by reaeration is proportional to the dissolved oxygen deficit.

The above assumptions were basic to the original Streeter-Phelps equations and have been accepted by numerous investigators since. However, the justification for the form of the other terms in the simulation model is not as simple:

(a) The dispersion term

As mentioned under section 7.4.2 the shape of the dye tracer curve in figure 7.6 is more consistent with the 'dead zone model' of Thackston and Schnelle (1970) than with the Taylor bulk diffusion curve. However it is doubtful whether such further refinement of the model would be of any value in this study considering the uncertainties in the database.

(b) The source/sink terms

Thomann (1972) refers to the inclusion of photosynthesis and respiration effects by means of constant terms over a reach as 'almost naive', an observation which could be said for all the BOD and DO sources and sinks. However the complexity of the processes involved prohibits a simple mathematical representation in the model and within the framework of our present state of knowledge and with the available data in this study it is the best that can be attempted. It is worth mentioning that more refined models have been developed for generating algal populations (e.g. Beck and Young, 1975) and some attempts to relate photosynthesis and respiration to the chlorophyll 'a' measure have been made (Thomann, 1972).

In addition, Velz (1970) shows how deposition and scour as well as the demand of sludge accumulations can be computed using a graphical method which can easily be adapted for computer simulation.

The half-sinusoidal diurnal variation of DO produced by photosynthesis is not consistent with observations which tend to indicate a mid-afternoon peak in the DO produced by this source (O'Connor and Di Toro, 1970). The effect of this is probably small and within the accuracy of the model as a whole.

9.2 The field surveys and sample analyses

Certainly the greatest problem encountered in this study was the aquisition of a suitable database from which statistically significant results could be obtained. The 100 samples taken during the twenty-four hour sampling survey on 21 March, 1979 is small when compared with the following extract from Chevereau (1973) describing a field survey undertaken for a modelling exercise similar to this study:

> 'During the survey more than 2 000 chemical and biochemical measurements were carried out, dissolved oxygen and temperature at three points were measured continuously, discharge was recorded by level recorders, and topographical data of the reach were collected to build a hydraulic mathematical model of the reach. In addition, rhodamine tests were performed to evaluate the longitudinal diffusion coefficients.
>
> Every two hours, mean samples were taken by automatic sampling apparatus, night and day, for seven days at several points of the model. The samples were automatically refrigerated and processed in a 20°C conditioned laboratory of the paper mill as soon as possible. The following parameters were measured for each sample: BOD_1, BOD_2, BOD_5, COD, the suspended solids, the pH, the dissolved oxygen and the temperature.'

The limiting factor in this study was the lack of laboratory facilities capable of handling large numbers of sample analyses in addition to their regular program, particularly where incubator storage was required as was the case with the BOD tests. Making use of commercial laboratories was not considered because, apart from the expense, with BOD analyses it is essential for reliable results that the laboratory technicians be experienced and familiar with the test; this would not be the case unless a laboratory undertakes such tests as a matter of routine. A further problem for surveys of longer duration would have been the personnel requirements for sampling since no automatic sampling facilities were available.

The survey of the river channel was at best very sketchy in the first two reaches, and for practical purposes non-existent in the lower reach where only coarse cross-section information from the highway construction were available. The reason for this lack of adequate channel data was the inaccessibility of the vlei areas. This resulted in the poor calculated estimates of the time of passage, and the need for dye tracer studies.

Flow determinations using surface velocities were necessarily rough, particularly as at none of the locations could a symmetrical distribution of velocity be assumed. In spite of this, the estimates made at the various locations were remarkably consistent (with the exception of station H(a)), but it must be borne in mind that the mean flow rate calculated from the surface velocities is very sensitive to the factor used in converting the surface velocities to mean velocities. Obviously a far better estimate of the flows could have been made using current meter determinations. However, it is considered that a reasonable estimate of the flow was made during both the July and March surveys and that the flow was roughly constant throughout the study reach. This latter observation was supported by the fact that the concentrations of chloride, a conservative constituent, in the samples did not vary along the reach.

The fact that there was a considerable time delay between the taking of some of the samples in the river and the analysis of the samples was a problem that considerably reduces the reliability of the analyses undertaken. Although attempts were made to keep the samples cool whilst in the field by using wet sacks, biochemical activity certainly continued to take place and the oxygen demand analyses made on the samples taken early in the survey are bound to be underestimated. The situation would have been improved if refrigeration facilities had been available for the samples as soon as they were taken.

The BOD data from the March survey was clearly inadequate for successful modelling. Not only were insufficient BOD_5 analyses undertaken but at the low levels of BOD_5 measured, the accuracy of the BOD test becomes doubtful. Ideally at least three BOD analyses should have been undertaken on hourly samples taken at each station; in this way greater confidence in the result could be obtained and the variability in the BOD levels reliably recorded. Such a survey would have resulted in around 300 samples for BOD analysis, well beyond the capabilities of the available laboratory facilities.

With only two 20-day BOD test analyses corresponding to 5-day BOD tests there was insufficient evidence to establish the ratio of BOD_{20} to BOD_5, especially as the analyses were not performed on the same samples. It was therefore decided to use a published factor of $BOD_{20} = 1{,}45\ BOD_5$ (Phelps, 1944). The use of this factor is subject to criticism (Chevereau, 1973), but is considered preferable to using the above limited data.

Somewhat more reliance could be placed on the COD analyses and for this reason modelling attempts were concentrated on this data. The problem here was to establish the inert or non-biodegradable fraction. Chevereau (1973) used COD as the ultimate BOD but in this study the evidence of three of the 20-day BOD tests undertaken suggested that around sixty percent of the COD was non-biodegradable. Clearly more 20-day BOD tests would have been desirable.

Marais and Ekama (1976) advocate the use of COD rather than BOD_5 in the analysis of wastewater and overcome the problem of the inert fraction in many of the relationships used in design by using the change in COD ($\triangle$ COD) rather than the absolute value of the COD. It is conceivable that a method of utilising $\triangle$ COD may be found for the equations of the dissolved oxygen balance in rivers which would considerably simplify the use of COD as a measure of oxygen demand in river models. The use of TOC is becoming increasingly popular due to the quick test used for its determination (see Appendix B). As with COD this would also require an estimate of the non-biodegradable fraction or the use of $\triangle$TOC.

9.3 Model calibration and verification

Three important points become apparent from the calibration:

(i) The model, with the available data base, was unable to describe the hourly fluctuations in BOD level in the river although a mean fit was achieved.

(ii) Sources and sinks of COD appear to play a large part in the oxygen balance process in the Klip River.

(iii) Estimates of as many parameters as possible should be made by other methods in order to reduce the number of parameters to be determined through calibration.

Each of these is dealt with in more detail below.

9.3.1 Inability of the model to describe the hourly fluctuations

The reason for the fact that the variability in the COD levels could not be modelled more closely, especially in the lower reaches, is probably due to three reasons:

(a) The inadequacy of the database to completely describe the variation in COD levels, especially at the upstream input end,

(b) The inability of the coupled equations to accurately describe all the processes taking place in the river, and

(c) The problem of the location of the sampling ploint at station F as mentioned in paragraph 7.2.1.

With the high variability in the COD levels in the river it was probably inadvisable to interpolate linearly between these values to obtain observed values for comparison with the simulated values at arbitrary output intervals. Calibration should, where possible, have been undertaken with output requested at exactly those times at which the observed values were obtained. However, in view of the second reason (b) above, it is unlikely that this would have made much difference to the calibration. The problem with the change of sampling point location at station F meant that incorrect data may have been used to establish the parameters in the first reach. This would throw out the calibration of the model in the reaches downstream of station F thereby making an hourly simulation of the oxygen balance difficult to achieve.

As long as the BOD cannot be simulated, the model cannot be said to be able to describe the system, no matter how well the simulated DO may fit the observed data.

The fact that a mean fit at each station could be obtained suggests that, although attempting to model the oxygen balance on an hourly basis may be too optimistic, a model of the average behaviour may be quite feasible. With such a model 3- or 5-point running averages could be used instead of the actual data. Larger scale models, covering study reaches of a hundred or more kilometres long could use 24 hour composite samples, i.e. samples taken at hourly intervals, but combined to give a single flow-weighted daily sample.

9.3.2 COD sources and sinks

The calibration results at station F apparently show evidence of a large source of COD in the first reach. This fact is apparent over the full twenty-four hour sampling period what makes it difficult to explain however, is that the results at station G require that a large sink be incorporated into the parameters for the second reach to reduce these high COD values in spite of the fact that the flow here is fast and well channelised. If it were not for this latter fact, a source of COD could be assumed to exist in reach E-F, probably originating from one or more of the smallholding farms or the Van Wyks Rust Pleasure Resort that border onto the river. Analysis of water from the only known farm reject, just above station F, indicated a negligible source of COD. (There is also the area of land irrigated with sewage effluent which may contribute, but it is felt that this effluent would have been fairly well purified by the time the return flow reached the river.) A possible reason may lie in the change of location of the sample point as mentioned in paragraph 7.2.1, although it is difficult to see why the COD values should be higher because of this. Furthermore, the model fit using COD data from the survey on 18 July, 1978, indicated somewhat smaller source and sink terms in the first and second reaches respectively. On the basis of the above it would appear that the observed COD values at station F should be treated with caution since no logical explanation can be made for such large sources and sinks in reaches 1 and 2.

9.3.3 Estimation of parameters

Figure 8.4 shows how a reasonably good fit of the DO curve could be obtained using very different values for the reaeration coefficient and DO source term. Although a reaeration coefficient value of 15 per day can be found in shallow turbulent streams, use of empirical formulae in section 7.5 indicated a more realistic value for the river reach in this study of 2,0 per day. As mentioned in section 8.2 'satisfactory' fits to the observed data could be achieved using different sets of parameter values and it is therefore necessary to constrain as many of these parameters as possible to narrow limits by means of either field measurements or empirical formulae. Paragraph 5.2 lists the various model parameters and possible methods of determination. Laboratory determinations of BOD decay coefficient, light and dark bottle tests, and benthal demand tests may only give a portion of the total parameter value being sought, but they do reduce the reliance on the calibration process to determine these values.

The sensitivity of the model to the assumed proportion of non-biodegradable COD suggests that attempts should be made to determine this fraction by means of a number of 20-day BOD tests.

Rinaldi, et al, (1979), shows that the parameters can be evaluated from a set of dissolved oxygen measurements plus only one BOD determination. This involves using a search technique to minimise the DO error. Due to the small variability in the DO measured in this study, and in the light of the above discussion on sensitivity, use of DO data alone to calibrate a simulation model by visual fitting would not be possible.

9.3.4 Comment on the parameter values obtained

9.3.4.1 COD calibration

(a) Photosynthetic production of dissolved oxygen

Fine tuning of the calibration process using the diurnal variation of DO produced by photosynthesis was only required in reach E-F. It is interesting to note here that it was in this reach that the surface of the water in the main channel was exposed to sunlight for most of the length of the reach, whereas in the other two reaches overhanging trees and reeds meant that much of these river reaches were in shadow. The value of 3 mg/l/day is consistent with the values obtained in light and dark bottle tests.

(b) Other parameters

With the exception of the BOD source/sink values already discussed, the estimates of the other parameter values all appear to be reasonable, although the cause of the DO sources could not be identified.

9.3.4.2 BOD calibration

By no means could the calibration attempt using BOD values be seen as an adequate fit (figure 8.3) and the parameters obtained will therefore not be considered further.

9.3.5 Minimum error calibration

The parameter values obtained by minimising the error compare well with those obtained by visual fitting. The improvement to the fit using the simulation model though, was possible through inclusion of a dispersion term, inert COD fraction and diurnal variation of photosynthetic DO. It is conceivable that further development of the method could lead to the inclusion of these other factors into the minimum error formulations.

The data preparation for this method is tedious and time consuming, and calibration by means of the simulation model is considerably quicker once the modeller is familiar with the program. This would be particularly so where much larger databases are used. In addition the results of the minimum error calibration must be viewed with caution; the fit giving the minimum sum of the errors may result from parameter values which are very unrealistic, the desired solution being near, but not quite at, the optimum. This was in fact shown to be possible with the program by imposing limits on some of the parameters, thereby drastically altering the set of parameter solutions, but only slightly increasing the sum of the errors.

This once again underlines the necessity for obtaining parameter estimates by other means.

In spite of the above reservations, the method could well have advantages, especially if some means of programming the data preparation can be devised.

9.3.6 Model verification

The results of the verification (figure 8.5) indicate a not unreasonable fit for the first two reaches. The discrepancy over the first six hour period at station G could well be due to the fact that linear interpolation was used between the observed COD values at 06h20 and 11h20 (see table C2). This is because the bottle containing the sample taken at 09h50 was broken during sampling. The fit is not as good in the reach between stations G and H, but this could be expected considering the uncertainties in the parameters obtained for this vlei area and the highway embankment construction.

It would appear from the verification that the source and sink of COD present in the first two reaches during the survey of 21 March 1979 were not as pronounced during the July survey. This is also evident from the parameters obtained by fitting the model to the July COD data (table 8.2) and is probably a result of the difference between the river regimes prevalent during the two surveys. In particular the flow during the July survey was higher than that of the March survey with the result that oxygen demands due to sludge deposits could have been scoured out. However, it should also be borne in mind that the March data at station F cannot be relied upon, as mentioned in section 7.2.1.

CHAPTER 10

SUMMARY AND CONCLUSIONS

10.1 Summary

The objective of this study was to develop mathematical models that could be used as an aid to regional planning of water and wastewater treatment facilities. Two aspects of the problem were studied:

(i) the development of an optimisation model for a sewage treatment plant, and

(ii) the development of a water quality simulation model for a simple river system.

A design simulation model was developed for an activated sludge sewage treatment plant based on design criteria generally accepted in overseas countries. It soon became apparent however, that these criteria were not entirely applicable to South African conditions where the tendency is to design for long sludge ages. This results in the effluent quality (in terms of the biochemical oxygen demand) no longer being a decision variable in the design process, and hence also not in the planning process for regional water quality. For this reason no further work was done on the wastewater treatment model.

A river model for simulating the biochemical oxygen demand (BOD) and dissolved oxygen (DO) balance in a river under constant flow conditions was developed using a finite difference form of the modified Streeter-Phelps equations. The two-step finite difference method of Dresnack and Dobbins (1968) was used to overcome problems associated with standard finite difference techniques. It was found that slight modifications to the method were necessary to allow for different sized time steps in step one and step two of the method in order to ensure stability of the calculation in step two. Other refinements included a function to allow for the diurnal variation of photosynthetic production of DO, and provision for the inclusion of the non-biodegradable fraction of the chemical oxygen demand (COD) in the data.

Calibrations of the model were carried out using COD, BOD and DO data from a 24-hour sampling survey, along a 5,8 km reach of the Klip River on 21 March, 1979, during which hourly COD and DO analyses and 3-hourly BOD analyses were performed. A new method of determining the river system parameters using the principle of minimising the error by means of linear programming was tried out and the results tested in the simulation model.

Verification of the model was attempted using COD data from a shorter sampling survey on 18 July 1978.

10.2 Conclusions

10.2.1 Optimisation of wastewater treatment plants

The current tendency in South Africa to design activated sludge treatment plants to operate at long sludge ages ensures a very high quality effluent in terms of the biochemical oxygen demand and therefore precludes the use of this variable as a decision variable in regional water quality planning. This does not however exclude the use of wastewater treatment plant optimisation submodels in regional planning models as other water quality indices, such as the degree of nitrification or denitrification required, may become the governing criteria.

10.2.2 Numerical procedure

The two-step finite difference technique used in the simulation model KLIP6 provides a simple method of solving the BOD-DO coupled equations for a dynamic river system, without some of the numerical problems inherent in the standard finite difference method. Finite difference methods are considerably more flexible than analytical solutions in the more complex river systems, especially where dispersion is significant as in this study.

10.2.3 Results of oxygen balance simulation of the Klip River

Despite what is considered to be a somewhat inadequate database, simulation of the COD and DO variation in a simple river system using the modified Streeter-Phelps equation was achieved with some success. Although it was not possible to fit the model to the hourly variation of the COD, a mean fit was achieved and, with the parameters so obtained, the model was able to roughly predict the system response to input from a separate set of data.

Although the inadequate database means that no definite conclusions can be drawn, some general inferences can be made:

(i) Where the stream is reasonably well confined to a channel, the modified Streeter-Phelps equations can be used to simulate the self-purification of a simple polluted river system. Where the stream becomes dispersed throughout a vlei area, such simulations may still be possible but a considerable amount of further research is required in this field, and alternative models, such as cell-type models, may have to be considered.

(ii) Parameters estimation based only on calibration of the model is difficult because of the large number of variables to be determined. The evaluation of certain parameters by acceptable alternative means, such as use of field tests and empirical formulae, could improve confidence in the remaining parameter values determined through calibration.

(iii) The nature of the sample analyses required for water quality modelling studies impose a limitation on the amount of 'observed' data that can be obtained. On the other hand, confidence in a model, particularly BOD-DO models which involve considerable simplifications of what are really very complex processes, is directly proportional to the amount of reliable data upon which it is based. It is therefore necessary that a considerably more extensive and reliable database is required to obtain an acceptable model for planning purposes.

(iv) The behaviour of a river system varies with different flow regimes and times of year. It is essential therefore, that data be collected for a variety of flow and seasonal conditions in order that the model should fully describe the system.

10.2.4 Parameter estimation by means of minimising the error

Providing caution is exercised in accepting the results of parameter estimation by minimising the sum of the errors, this method provides a direct means of calibrating a mathematical model of the BOD-DO balance in rivers. The data preparation for this method is at present tedious and time consuming but lends itself to programming on the computer which will make the method considerably more attractive.

10.2.5 Dispersion in the Klip River

The results of the tracer analysis in reach 2 confirm reports by other workers that longitudinal dispersion in well channelised streams is often negligible (Chevereau, 1973; Thomann, 1972). But this is clearly not the case in the vlei areas of the Klip River, even though the flow may be still fairly well confined to a channel. Since vleis are a predominant feature of most rivers on the southern Witwatersrand, future modelling in this area